THE CASE FOR RENEWED HUMAN EXPLORATION OF THE MOON

PAUL D. SPUDIS
Lunar and Planetary Institute, 3600 Bay Area Boulevard, Houston, TX 77058, USA
E-mail: Spudis@lpi.usra.edu

Abstract. A human return to the Moon will be a boon to science. On the Moon, we can learn about the geological processes that have shaped all of the terrestrial planets by studying the well-preserved record of the Moon. The Moon is a superb platform for the observation of the universe and sensitive instruments designed to take advantage of its unique environment will allow us to see more of the universe more clearly. Both of these objectives require the guiding presence of human intelligence, flexibility, decision-making, and adaptation. Human field work is required to solve many scientific problems. Experience has shown that human installation and maintenance of complex equipment in space is often required. No one has yet built a robot that duplicates or comes close to human judgement and flexibility. Beyond the sheer adventure of human spaceflight, people are needed to carry out the complex, second-generation scientific exploration of the planets.

Keywords: Exploration, field science, human space flight, lunar base, Moon, reconnaissance, robotic space flight, telepresence

1. Introduction

In the debate that currently rages on future directions for the space program, human missions to Mars receive a great deal of media attention. I believe that a human return to the Moon makes more sense fiscally, politically, and operationally. As Earth's nearest neighbor in space, the Moon makes a logical stepping stone to destinations in the solar system farther afield. In this paper, I first lay out the reasons why I believe the Moon to be the logical next destination. Then, I consider the advantages and drawbacks to two principal modes of exploration – with machines and with people. Finally, I consider the possible policy implications of a lunar return and why such a program is the best next step in space.

2. Why the Moon?

The Earth's Moon is a strategic asset in many ways. It's proximity means that it is readily accessible, with launch opportunities available virtually constantly. As the Moon is only a few days away by spacecraft, missions can be sent to the Moon, operated from either the Earth or the Moon, and completed within a week. Such proximity eliminates the long, event-poor transits of planetary missions.

Earth, Moon and Planets **87:** 159–171, 2001.
© 2001 *Kluwer Academic Publishers. Printed in the Netherlands.*

But the Moon is far enough away from the Earth to have value as a proving ground for future planetary missions. On the Moon, we can rehearse both the operational and scientific tasks that we hope to accomplish on future missions farther afield. Operations include the arrival and departure of surface excursions, erecting and maintaining surface habitats, production and recycling of consumables, the use of in situ materials for a variety of purposes, and the physiological and psychological rigors of human presence off-planet for extended periods. For exploration, we can study the variety of human and machine strategies and tactics in order to learn how to best leverage the simultaneous presence of both capabilities in planetary environments. By using the Moon as a natural test bed for such activities, we lessen risk for future missions and gain valuable operational experience for the time when we do venture farther afield.

A return to the Moon offers many opportunities for science. The geological processes that operate on all the rocky bodies of our Solar System have occurred on the Moon (e.g., Spudis, 1996). We can study impacts, volcanism and the deformation of the Moon's crust to understand better those processes on the other planets. Moreover, the Moon's proximity to the Earth allows us to use the passive lunar surface as a "witness plate" to the environment of near-Earth space for the last few billion years. Such study includes both the use of the uniquely preserved record of solid body impact on the Moon and its collection of solar and galactic particles in the regolith. By studying the geological processes and materials of the Moon, we can not only unravel its complicated and fascinating history, but also read past chapters of Earth's history, chapters that are erased or were never present in the dynamic geological environment of the Earth.

The Moon is a superb platform for astronomical observation. It has no atmosphere, a cold, dark sky, a fourteen-day "nighttime" and a seismically stable landscape, enabling the construction and use of very sensitive instruments, such as optical interferometers. Instruments of this type would permit sky observations at incredible resolutions, approaching micro-(10^{-6}) arcseconds (e.g., Mumma and Smith, 1990). Among the phenomena observable with such instruments would be star spots, the structure of planetary nebulae, and the full disks of terrestrial planets orbiting nearby stars. The entire electromagnetic spectrum, from DC to gamma-rays, is visible from the Moon's surface. Moreover, the vacuum, cold environment on the Moon allows the observation of the sky in wavelengths that are difficult or impossible to observe from the Earth. Far infrared observations can be made using passive cooling of detectors. The far side of the Moon is the only known place in the Solar System that is permanently shielded from the radio noise and static of Earth, permitting observations in totally new parts of the radio spectrum. Every time a new portion of the spectrum has been observed, new discoveries have been made.

In addition to these advances in the physical sciences, biological and medical science would benefit (e.g., Ponnamperuma and Gehrke, 1992). We know nothing about the human adaptation process to reduced gravity. Study of human biomedicine on the Moon will give us valuable data on adaptation to gravity less than that of the Earth. The effects of reduced gravity on cell reproduction and growth are likewise poorly known and experiments on the Moon will provide valuable data points. By returning to the Moon, we will learn to live and work in space. We can here acquire the skills needed to survive off-planet and prepare for human travel beyond the Moon. Such experience includes not only the testing of equipment and techniques, but also understanding the social complexities of humanity's first foothold on another world. It makes sense to learn these undoubtedly difficult lessons on a planet only 3 days from Earth, rather than on one requiring a year for return.

A lunar return is the next logical goal in space. From lunar flights, we can gain experience and confidence in human planetary flight operations. We can learn the best ways to explore planets, using both robotic and human means. We can study the history of the Moon and all of the terrestrial planets, including the Earth, by reading the geological record of the Moon. We can use the Moon as an observing platform to examine the universe around us in unprecedented detail. And we can learn about ourselves – how we can best equip and adapt ourselves to the longer, more demanding planetary journeys of the future.

3. Why People?

On July 21, 1989, President George Bush proposed that the United States commit itself to a return to the Moon and an expeditionary journey to the planet Mars to commemorate the 20th anniversary of Apollo 11, the first lunar landing. This bold announcement, with its Kennedyesque echoes, generated much excitement in space circles. The hope was that a new "golden age" of space exploration was imminent, but the new initiative was never funded by the Congress and was suspended indefinitely.

Hidden in space policy debates is a fundamental, philosophical argument on the role people have in space exploration, specifically, the value (or lack thereof) of human spaceflight (e.g., cf. Slakey, 1999; Spudis, 1992, 1999). This debate has been going on since spaceflight began and shows no sign of becoming any less fervent (on either side) with the passing of time. Questioning the value of human spaceflight comes from many quarters, from observers of differing agendas. Some question the value of increased expenditure in space, contending that NASA already has a "full plate" of tasks to accomplish. One common criticism comes from the scientific community, some of whom question the *scientific* value of humans in space. Their argument is that human spaceflight is an expensive "stunt" and that science goals can be more easily and satisfactorily accomplished by robotic spacecraft. This argument has become an article of faith in those scientific circles that prefer robotic missions.

It has been forty years since Yuri Gagarin and Alan Shepard made the first human flights into space and it astounds me that the debate over the relative merits of people and machines as instruments of exploration of space still rages. Human capability is required in space to install and maintain complex surface instruments and to conduct field exploration. These tasks take advantage of human flexibility, experience, and judgment. They demand tasks and skills that are unlikely to be automated within the foreseeable future. A program of purely robotic exploration is inadequate in addressing the important scientific issues that make the planets worthy of detailed study.

3.1. INSTALLING AND MAINTAINING SENSITIVE EQUIPMENT

Geophysical networks (seismic, magnetic, and thermal instruments), astronomical (telescopes, interferometers), and instruments to measure other physical properties (spectrometers, particles and fields experiments) require careful emplacement, alignment, and operation to work properly. Elaborate techniques have been envisioned to allow remote emplacement of such instruments by a variety of robotic techniques (e.g., penetrators, surface rovers, etc.). These methods have yet to be demonstrated in actual space operations. Very sensitive instruments need to achieve certain precision and cannot tolerate the rough handling of robotic deployment.

We have several years experience with human deployment of instruments, both in space (Hubble Telescope) and on planetary surfaces (the Apollo Lunar Surface Experiments). In the case of the Space Telescope, both repair of the originally flawed instrument and continued maintenance of this delicate machine has been ably accomplished by astronauts on servicing missions. The Apollo surface network gave us a detailed picture of the interior of the Moon and its interaction with space. These experiments (which operated flawlessly for over eight years until shut down in 1978 for fiscal, not technical, reasons) had to be carefully set-out and aligned in order to work properly. Although one can envision potential robotic solutions to the problem of the deployment of complex instruments, the auto-deployed versions of such networks are always of lower sensitivity and capability than their human-deployed counterparts.

Sometimes things break. For space hardware, this can be catastrophic (as in the loss of the *Challenger* shuttle or the mysterious loss of the *Mars Observer* spacecraft) or merely annoying (as in the failure of the radio antenna to deploy on the *Galileo* spacecraft). Typically, equipment that fails in space is written off as a costly loss. On several occasions, however, people have demonstrated their incomparable value by repairing hardware in space, saving missions and the precious scientific data that they produce. The *Skylab* mission in 1973 was in serious jeopardy of being a complete loss. On launch, the thermal heat shield was torn off the lab, a solar panel was lost, and the other panel, bound tightly to the lab by restraining ties, would not release. The crew of *Skylab 2* (Pete Conrad, Joe Kerwin, and Paul Weitz), through innovative problem solving and heroic effort, installed a new thermal shield and were able to deploy the pinned solar panel. These human efforts saved not only their mission but the entire Skylab program.

Of course, some failures are too severe and cannot be repaired, as in the crippled *Apollo 13* spacecraft. But humans have the unique ability to analyze problems and come up with innovative solutions, and to make real-time, on-the-spot judgments. Machines are capable of limited self-repair, usually through the expedient of redundant systems, but do not possess the flexibility of having people on the spot. Machines can be designed to fix the “expected” problems, but so far, only people have shown the ability to handle the unforeseen ones.

3.2. HUMANS AS FIELD SCIENTISTS

Exploration has two broad categories: reconnaissance and field study (Spudis and Taylor, 1992; Taylor and Spudis, 1992). The goals of reconnaissance are to acquire a broad overview of the compositions, processes, and history of a given area, region, or planet. Questions asked during the reconnaissance phase tend to be general, first-order, and of an exploratory nature (e.g., What’s there?). Examples of geological reconnaissance are an orbiting spacecraft performing global mapping, an automated lander measuring the chemical composition of the soil, or even the first lunar landings by the Apollo astronauts. The first, crucial steps of exploration are tentative, exploratory, and characterize what is there.

The goals of field study are more ambitious. The object is to understand planetary or biological processes and history at whatever levels of detail are appropriate. This requires observation in the field, the mental building of a conceptual model, hypothesis formulation and testing, done with repeated visits to the same geographic location. Field study is an open ended, ongoing activity; some field sites on the Earth have been studied continuously for over a hundred years and still continue to yield new and important insights. Field study requires the guiding presence of human intelligence and is not a simple matter of collecting data, but is the process of analyzing data in the field and applying these insights on a continuing basis to formulate increasingly more sophisticated and complex questions.

The transition from reconnaissance to field study is fuzzy and equivocal. In any exploration, reconnaissance dominates the earliest phases of study with the gathering of information about the materials that make up the study area and the processes that have operated there. However, at some stage, enough data are collected that questions are formulated and answered with more sophistication and complexity. Sometimes, imperceptibly, the problems require “hands on” interaction of the scientist with the environment and gradually, the boundary between reconnaissance and field work is crossed.

Because the nature of reconnaissance is toward simple, focused tasks and the questions are broadly based, it is the type of exploration most suited to robots. A wide variety of robotic missions are possible that can provide general information of planetary bodies on global to local scales. Orbiters can map the surface features of planets at a variety of resolutions, landers can determine the surface characteristics and composition of materials. Rovers can traverse the surface, testing the lateral variations of physical and chemical properties and collecting samples for return to Earth.

The fundamental requirement of field study is the guiding presence of human intelligence during the work. Field study is complicated, interpretive, and protracted. Moreover, the plan of problem solution is not immediately apparent before, and sometimes during, the field work but must be formulated, applied, and significantly modified in real time. Most importantly, field work nearly always involves uncovering the unexpected and in this type of work, discoveries can be exploited to a degree not possible during simple reconnaissance. Sometimes such exploitation calls for exploration methods and techniques completely different from those originally envisioned.

The difference between the needs of reconnaissance and field study is essentially the difference between robotic and human contributions to scientific exploration. Robotic spacecraft can and do make significant and impressive advances in our knowledge. They can take us to remote and distant realms and give us a look at and feel for the strange nature of alien worlds. But they cannot undertake scientific study, make new observations and let these observations guide subsequent work and iteratively apply the lessons learned to an evolving conceptual paradigm. Herein lies the unique contributions of humans: to discover and to act upon such discovery, in near real-time. Although significant gathering of data can be done with robots, conducting science in space requires *scientists*.

3.3. THE MELDING OF MIND AND MACHINE

Human dexterity and intelligence is the prime requirement of field study. Does this require the physical presence of people? The concept of *telepresence*, the remote projection of the abilities of a human mind into a machine, may permit field study on planetary surfaces without the danger and logistical problems associated with human space flight. In telepresence, vision, touch, and locomotion of the human operator are electronically transmitted to a robot on a planet's surface. The fidelity of vision and feedback of touch and locomotion senses gives the human operator the sensation of being present on the planet's surface, "inside" the robot. As a bonus, the robot surrogate can be given enhanced sensory capabilities (e.g., infrared vision), great strength, and endurance, all while the human resides and operates the robot in safety and comfort at the remote location (e.g., Taylor and Spudis, 1992).

If robotic telepresence is such a great idea, why do we need for humans in space? Although the technology for telepresence is not particularly difficult to achieve, it is not yet available. Vision is the lion's share of sensory ability used in field study and any telepresent system needs very high-definition imaging, approaching human capability (normal (20/20) human vision resolves $30''$ of arc, roughly equivalent to 10,000-line television). Such real-time imaging systems and the data subsystems needed to support them have not been developed. More importantly, the most serious questions regarding telepresence are not technological, but psychological. Knowledge of human factors, the nature of intuitive problem solving, and the behavior of real scientists in field situations are either poorly understood or almost completely unknown. One cannot simulate what is not understood. Abstract descriptions of the complexity of field work often fail to convince those who have never done it and thus, cannot convey the true nature of the experience.

Finally, there is the critical problem of time delay in communicating through telepresence. True telepresence requires instantaneous response between command, execution, and observation of effect. The distances in space are so vast that instantaneous response is impossible between the robot on the distant planet and its operator on Earth (even to the Moon, round trip signal time is 2.6 seconds, a seemingly rapid but in fact quite cumbersome delay, as video from the Apollo missions demonstrate). Time delays between Earth and Mars are even greater (up to 40 minutes round-trip) making true telepresence impossible. Remote operation *is* possible, but this reduces the operator-machine interface to a cumbersome, ineffective mechanism where physical manipulation, not exploration, becomes the primary preoccupation. Minds cannot roam free if shackled in time-delayed, robotic chains.

Robots and machines are tools; their judicious use can reduce risk, increase effectiveness, and add variety to our exploration of the planets. They are not now and will never be replacements for people. While some profess faith in the promise of artificial intelligence, its promise remains just that and so far, has fallen far short of what we require for even the most rudimentary forms of field science. Telepresence is a promising technique to extend human reach, but can never be an acceptable substitute for human explorers. Scientific exploration is like all exploration; its primary motivation is emotional, not logical. No robotic surrogate can ever replace the inspirational power, even the vicarious one, of the *human* explorer, working on another planet.

3.4. SCIENCE AND EXPLORATION

If one of the goals of our space program is to study the universe and understand the nature of our Solar System, human exploration must be a part of it. Currently, our immediate focus in space is on the construction of the International Space Station (ISS). The ISS is not a destination, however, only a place to learn how to roam farther afield. While some scientific research will be done on it, its real value is to teach us how to live and work in space; on-orbit assembly of complex vehicles is a task that we must master to achieve greater exploration capability. Afterwards, the Moon is both a natural laboratory and planetary test-bed where we can study solar system history, observe the universe with sensitive instruments, and learn how to live on another planetary body. By living and working on the Moon, we can perfect the technique of telepresence and learn how to use people and machines to their best effect in planetary exploration.

Robotic missions are much less costly than human missions; I contend that they are also much less capable. The robotic Soviet Luna 16, 20, and 24 sample-return spacecraft often are cited as examples of cost-effective ways to return samples from the Moon. In fact, the results from these missions alone are virtually incomprehensible without the paradigm provided by the results from the manned Apollo program. The context of samples collected by Apollo is known, both regionally and locally, while the Luna samples are just "grab" samples from a known geographic location. During Apollo, the geologically trained astronauts were able to select the most representative samples of a given locality and recognize interesting or exotic rocks and act on such discoveries in real time. Consequently, we understand the geological make-up and structure of each Apollo site in much greater detail than we do the structure of the Luna sites. This knowledge makes the tiny sample from Luna much more valuable; thanks to Apollo, we understand the geological style and context of the Moon.

For a contemporary analog, consider the Mars Pathfinder mission, widely touted as a major scientific success. While Pathfinder did discover an unusual, silica-rich rock type, because of its limitations, we do not know whether this composition represents an igneous rock (crystallized from an internally generated magma), an impact breccia (a conglomerate made up of many different kinds of rock), or a sedimentary rock (compacted, fine-grained debris). Each mode of origin has widely different meaning for Martian history. As the geological context of this sample is totally unknown, this astounding discovery has negligible *scientific* value and impact. A trained human geologist could have made a field identification of the rock type in a few minutes, giving context and meaning to subsequent chemical analysis and making the scientific return substantially greater.

When a space scientist talks about science in space, he usually means "my science". Those that speak of human spaceflight as wasteful and irrelevant typically neither need nor desire the presence of humans to perform their science. In some instances, such as in the study of plasmas and magnetic fields, the phenomena to be studied are not detectable by human senses and the presence of people is irrelevant. In other cases, people may actually interfere with the phenomenon under study. If one is studying the tenuous lunar atmosphere, outgassing from an astronaut's suit can completely overwhelm and mask the native atmospheric gases. People not only are not *needed* in this case – they interfere with the investigation to be conducted.

Facts regarding the physical state of another planet can be gathered efficiently by machines. Understanding of that simple data occurs on the ground, where humans examine, comprehend, and study it. The problem comes when you are studying a phenomenon for which the data are over-abundant. Which data should be collected? Which should be ignored? Which data are the most important to solve the problem at hand? What is the question to be answered? How do you know that you are solving the problem that you think you are solving? Or even collecting the right data to solve a problem?

So what is the purpose of our space program: Science or exploration? I firmly believe that not only should exploration be the goal, but that exploration *is more important* than science. The desire to probe new territory, to see what's over the hill, to have our imaginations challenged and broadened is the essence of exploration. Science always follows exploration; it is our incomplete and generally inadequate attempt to describe and explain nature. Exploration is something more primal: It is our effort to advance the species. By broadening the imagination, alternative strategies for coping with the universe are revealed and provides us with an evolutionary advantage.

To directly answer the question "robots or humans?", one must define the task. If space exploration is about going to new worlds and understanding our universe in ever increasing detail, but in an effective and efficient manner, the answer must be: "both". The strengths of each partner in exploration make up for the other's weaknesses. To use one technique to the exclusion of the other is to foolishly deprive ourselves of the best of both worlds: the human thrill of personal participation and the beneficial use of robotic assistance.

3.5. THE NEXT GOALS IN SPACE

Ask almost anyone at NASA what their next big goal is and they will answer "Mars". The science division has a detailed plan for robotic exploration of the Red Planet, culminating with a series of sample return missions late in the first decade of the new century. These advanced robotic missions are preludes to human journeys. Advanced studies focus almost exclusively on human missions to the red planet and the search for evidence of former or existing Martian life.

The problem with this grand scheme is that it won't happen. Simply put, no matter how it has been approached, repackaged, scaled-back, or re-invented in the last seven years, the reality is that human missions to Mars, costing hundreds of billions of dollars and needing time spans of decades, have had and will continue to have negligible success at getting started.

There is no room in the federal budget for a project of this magnitude. The fraction of the "discretionary" money in the budget steadily decreases with time as the "mandatory" entitlements take up ever increasing fractions of government expenditures. To obtain long-term government funding, a technical project must relate to some overriding national priority and must produce payback on time scales commensurate with political terms of office (4–6 years).

The history of the United States shows that only two kinds of big engineering projects enjoy long-term funding stability: those related to national defense (e.g., the Panama canal, the Apollo program) and those that build and maintain our economic infrastructure (e.g., the TVA project, the interstate highway system). Neither the search for worlds around other stars nor extraterrestrial life fit into those categories. Thus, they will never be funded at levels permitting significant levels of human activity. And if there are no people in space, an activity that marshals and crystallizes the lukewarm public support the space program enjoys, NASA will whither away.

For the last 30 years, NASA has maintained an Apollo management-style without a long-term space goal. These years have largely been spent engaged in bureaucratic struggles to survive. Scientific and engineering talent has drifted away through attrition and retirement and innovative ideas and clever plans have been lost or buried.

What's the alternative to NASA's demise? We must return people to the Moon. A lunar return is achievable within five years, at costs an order of magnitude lower than that of a manned Mars mission. Recently water ice deposits were discovered in permanently dark areas near the poles of the Moon (Nozette et al., 1996). The surrounding mountain peaks are bathed in near constant sunlight (Bussey et al., 1999). This terrain is one of the most valuable pieces of real estate in the inner Solar System. The potential for economic explosion, scientific discovery and national security is staggering. The polar ice can support human life, both as water and as breathable oxygen derived from it. We can also use the hydrogen and oxygen extracted from water as rocket propellant. With launch costs approaching $50,000 per pound to low Earth orbit by Shuttle, one can see that the value of over 10 billion tons of water ice located in the lunar polar regions is considerable.

By developing the infrastructure for operations on the Moon, we obtain routine human access to GEO, or geosynchronous orbit, the 23,000 mile high zone where all Earth's communication satellites orbit. Why is this important? The next generation of comsats will be enormously heavy, complex machines, requiring megawatts of power and maintenance by people. Such satellites will be needed as demand for bandwidth, the prime commodity of the 21st century information society, increases exponentially. The ice deposits on the Moon will provide propellant to help support the Earth-Moon transportation infrastructure. Using lunar propellant, we can access GEO with machine and human capability to build, service, and operate the comsats of the new century. Such capability would be worth literally trillions of dollars.

The US has a unique opportunity to accomplish important national goals. A return to the Moon will aid US security by giving the United States access to valuable lunar resources (our first, off-world "El Dorado"), and will augment our expanding economic infrastructure by providing routine access to all "energy levels" of Earth-orbital space operations. A program to return to the Moon ties NASA to important national priorities and makes it a player in a burgeoning and emerging Solar System economy. The Moon gives NASA an exciting, vigorous mission and paves the way to the planets beyond.

Acknowledgement

This paper is Lunar and Planetary Institute Contribution No. 1103.

References

Bussey, D. B. J., Spudis, P. D., and Robinson, M. S.: 1999, 'Illumination Conditions at the Lunar South Pole', *Geophys. Res. Lett.* **26**, 1187.

Mumma, M. J. and Smith H. J. (eds.): 1990, *Astrophysics from the Moon*, AIP Conference Proceedings 207, 656 pp.

Nozette S., Lichtenburg C., Spudis P.D., Bonner R., Ort, W., Malaret E., Robinson, M., and Shoemaker, E. M.: 1996, 'The Clementine Bistatic Radar Experiment', *Science* **274**, 1495–1498.

Ponnamperuma C. and Gehrke C. W. (eds.): 1992, *A Lunar-Based Chemical Analysis Laboratory*, Proceedings of the Ninth College Park Colloquium. Chemical Evolution, Deepak, Hampton VA, 281 pp.

Slakey F.: 1999, 'Robots v. Humans: Who Should Explore Space? Robots', *Sci. American Presents*, *Future of Space Exploration* **10**, 24.

Spudis P. D.: 1992, 'An argument for Human Exploration of the Moon and Mars', *Amer. Scientist* **80**, 269–277.

Spudis P. D.: 1996, *The Once and Future Moon*, Smithsonian Institution University Press, Washington DC, 308 pp.

Spudis P. D.: 1999, 'Robots v. Humans: Who Should Explore Space? Humans', *Sci. American Presents*, *Future of Space Exploration* **10**, 25.

Spudis, P. D. and Taylor G. J.: 1990, 'Rationale and Requirements for Lunar Exploration', in *Engineering, Construction, and Operations in Space II*, Proceedings of Space 90, Vol. 1, pp. 236–244.

Taylor, G. J. and Spudis P. D.: 1990, 'A Teleoperated Robotic Field Geologist', in *Engineering, Construction, and Operations in Space II*, Proceedings of Space 90, Vol. 1, pp. 246–255.

Discussion

Mr. William Marshall (University of Oxford): You outlined many good scientific reasons for manned exploration of the Moon. Which non-scientific reasons would you advocate?

Dr. Spudis: Whenever people have gone to a new environment we have always obtained some unexpected benefit, and usually this involves a change in perspective. A lot was written after the Apollo 8 mission in December 1968 when they took the famous "Earth-rise over the Moon" picture – the first time people had seen the Earth in space as a planet. This was a change in perspective. It really did revolutionise consciousness, the idea of the Earth as a global unit. I think we will see something very similar to that if people are back on the Moon. And we will see it probably in areas we don't expect. I think people living off-planet will be a new kind of perspective, and what that might mean for culture might be quite profound.

Certainly, science has always influenced culture, and living on the Moon, living off-planet, will do the same, probably in ways we cannot predict.

Mr. Horace Regnart: Could you comment on the risk to the high vacuum of the Moon from possible contamination by gasses released in the course of exploration?

Dr. Spudis: Yes, if you have a significant amount of activity on the Moon you will build up an artificial atmosphere. This has been studied – some of the best data come from the Apollo landings, where each lunar landing temporarily doubled the lunar atmosphere. This temporary atmosphere dissipated within one to two months of each landing. Continuous activity will probably build up a local atmosphere, but it remains to be studied how this effect dissipates the further you move from the site of activity. My feeling is that it is probably a very localised effect, but we won't know until we get back to study it. Actually, we need to perform experiments by releasing large quantities of gasses on the Moon, and then study how they dissipate as a function of distance from the point of origin.

Dr. Chris Trayner (University of Leeds): You mentioned that much of what a geologist does is stand, look, and think. This suggests that your telepresence concept can be finessed. For the cost of such a device you could probably send several simpler ones. These could have simple rover mobility, a camera, and perhaps sample collection facilities. Each could be operated by one or two geologists on Earth, who could then brief the geologist in the spacecraft to investigate the most promising sites.

Dr. Spudis: That's absolutely right, and its what I was getting at when I talked about learning to use people and machines together effectively. You let the robotic rovers go out and do the reconnaissance, and then you let the people follow up with detailed fieldwork.

Mr. William Marshall (University of Oxford): One of the main problems with a manned return to the Moon may be the "been there, done that" mindset. How would you suggest we get over that attitude, especially in the context of manned Mars exploration?

Dr. Spudis: That's an interesting point, and its one I come up against all the time. Usually I try to give a very detailed response along the lines that the Moon has the same surface area as Africa, and we've only landed in six places and hardly scratched the surface . . . But basically my feeling is that when people argue like that they're not really arguing against the Moon, but are arguing against exploring at all. They are saying "I know enough about that, and I find it uninteresting, and I don't need to go back". I'd just point out that the same thing was said about Australia initially. . . .

With respect to the place of the Moon in the Mars programme, I think the Moon is a stepping stone to wherever else you want to go. I certainly don't advocate going to the Moon and stopping there. You go to the Moon to learn what you need to know to go anywhere else in the Solar System, Mars included. All the operational, technical and scientific experience you will gain on the Moon is applicable to any future planetary exploration you may undertake. Going to the Moon is not a detour, it is actually a stepping stone along the way.

Mr. William Clarkson (University of Southampton): If an observatory is placed on the Moon, is there a problem with impacts to worry about? The lack of an atmosphere will mean that any approaching body will impact the surface. What effect does this have on the stability of the surface as an observing platform, and will dust kicked up by impacts affect the clarity of the sky above the telescope?

Dr. Spudis: Impacts which generate enough seismic energy to be felt over distances of a few hundred km are very rare. Dust may be a problem, and all these environmental issues will have to be studied – although I believe they will all prove to have technical solutions.

Dr. Andrew Coates (Mullard Space Science Laboratory, UCL): To return to the issue of cost: do you have an estimate for the "science per dollar" for manned compared to robotic missions to the Moon?

Dr. Spudis: If you want to talk about cost you have to talk about what the programme is designed to do from a societal basis, not a scientific one. I don't pretend that we are going to go back to the Moon for science alone, we're going to go back for a lot of different reasons. I think, fundamentally, the reason we'll go back is to industrialize cislunar space. I mentioned the commercial applications of geostationary orbit (GEO) – eventually you will need to get people up to GEO for short periods of time to perform maintenance and assembly tasks. I think we'll go back to the Moon primarily to develop the transportation infrastructure to enable us to do that. However, given that this is done primarily for commercial reasons, this opens a scientific opportunity.

As to the cost, *technically* there is no reason why we could not be back on the Moon in six years for $50 billion or less. I know nobody believes that, but I believe it because I know what the hardware costs, and what it will cost to employ the people needed to do it, building on the existing infrastructure.